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RESEARCH ARTICLE

# Life Cycle Assessment of Packaging Systems for Enteral Nutrition Products: Multilayer Pouch and High-Density Polyethylene Bottle

**Martina Krueger***
ifeu - Institut für Energie- und Umweltforschung Heidelberg gGmbH

**Benedikt Kauertz**
ifeu - Institut für Energie- und Umweltforschung Heidelberg gGmbH

**Claudia Mayer**
ifeu - Institut für Energie- und Umweltforschung Heidelberg gGmbH

## ABSTRACT

*Environmental performance of alternative packaging options for a given product application increasingly comes into awareness, both at the end consumer level as well as in the field of business-to-business communication. The purpose of the study presented here is to examine the environmental performance of a multilayer pouch for packing of enteral nutrition products. To achieve this, a life cycle assessment has been conducted. As an attributional full cradle-to-grave life cycle assessment it compares environmental impacts of a comparable lighter multilayer pouch vs. two different comparable heavier high-density polyethylene bottles (covering the weight range of high-density polyethylene bottles on global markets for enteral nutrition products) in two different sizes (500 mL and 1000 mL). All life cycle steps are taken into account: from the extraction and production of packaging raw materials over converting and filling processes to all transports as well as recycling and/or final waste disposal (landfill and/or incineration) of the packaging materials after their use. The functional unit of this study is the packaging required to deliver 1000 liters enteral nutrition product to the customer at the hospital. The study aims to cover various markets: Europe, Latin America and Australia. To depict the different markets, a cluster approach was chosen. The clusters are based on two criteria: geography of target markets, which determines the distribution (truck and/or ship) and transportation distances; as well as the end-of-life final waste treatment routes – either landfill or incineration. An essential difference between the two product types (multilayer pouch and high-density polyethylene bottle) is the mechanical recycling option for the high-density polyethylene bottle, which is currently not applicable for the multilayer pouch at a commercialized level. The results of the study show that the multilayer pouch packaging system is favorable from an environmental point of view versus alternative high-density polyethylene bottle systems in the field of enteral nutrition products. The ecologic advantage of the multilayer pouch system is based on the reduced initial material use compared to high-density polyethylene bottles requiring a higher polymer amount in production. This applies to both sizes and all geographic clusters taking into account the mechanical recyclability of the high-density polyethylene bottles.*

## KEY WORDS

*LCA, multilayer pouch packaging, HDPE bottles, sustainable healthcare, enteral nutrition product, environmental sustainability flexible packaging*

* **Martina Krueger**
*Corresponding Author*
martina.krueger@ifeu.de

## 1 INTRODUCTION

Over the last years, packaging waste has increased (e.g. 17 % from 2010 to 2017 in Germany) and thereby its environmental relevance [UBA 2019]. Therefore, it is getting more and more important to look at the environmental performance of packaging. Looking at data for packaging consumption, the consumption of plastic packaging has increased by over 70 % from 2000 until today in Germany [UBA 2019]. Furthermore, also at the European level environmental sustainability issues related to plastic packaging gain importance, as can be seen e.g. by the development of the European plastic strategy [European Commission 2018]. Although they might not be the first to come to mind, hospitals contribute to a considerable part to overall packaging waste [REMONDIS 2017]. For example, in Germany for one hospital patient six kilogram waste are generated on average [Berufsgenossenschaft für Gesundheitsdienst und Wohlfahrtspflege 2019]. Additionally, worldwide expenditures in the healthcare sector are growing [World Health Organization 2020; Leiden et al. 2020] with for example 19,808,687 patients being released from hospital in Germany within the year 2018 [Statistisches Bundesamt 2020], which would lead to 118,852,122 kg waste in total taking the figure mentioned above into account. Nevertheless, to the best knowledge to the authors, life cycle assessment (LCA) studies in the healthcare packaging sector are relatively rare [Ali et al. 2016].

Apart from the public awareness, environmental sustainability has also gained importance in very specific business-to-business markets including but not limited to healthcare. One example is the relevance of sustainability criteria in procurement for hospitals, e.g. regarding enteral nutrition products. With a market size of € 9 billion, clinical nutrition products are not insignificant for packaging waste from the healthcare sector [Fresenius 2019]. Due to the non-recyclability of multilayer pouches at a commercial level, the general perception of these packaging systems is often negative regarding the environmental performance. Therefore, a life cycle assessment was conducted to examine the environmental performance of a multilayer pouch packaging system for enteral nutrition products (tube feed formulas ) and two high-density polyethylene (HDPE) bottle packaging systems for the same indication. The named container types are currently used as common packaging systems for enteral nutrition products on different continents. The LCA was carried out by ifeu Heidelberg and commissioned by Fresenius Kabi.

Furthermore, composite packaging increasingly gains public attention regarding its environmental sustainability along with current aims towards a circular economy. An indication here is the setting of mechanical recycling targets for polymer packaging as a result of the development of the European plastics strategy [European Commission 2018].Before this background, the main objective of this study was to provide insights into the environmental performance of multilayer pouch and HDPE bottle packaging systems for enteral nutrition products. Fresenius Kabi currently globally uses such multi-layer pouches for packaging their products, whereas HDPE bottles are also a common packaging type for such tube feeds on a global level.

## 2 METHODOLOGY

The LCA in this study is designed as an attributional “cradle-to-grave” LCA and includes the extraction and production of packaging raw materials, converting and filling processes, all transports as well as recycling and/or final waste disposal (landfill and/or incineration) of the packaging materials after their use. Attributional LCA methodology is selected as clearly the study aims to examine and compare environmental impacts of the two examined packaging product types that are common for enteral nutrition products. The LCA is based on the ISO 14040/14044 principles [ISO 14040 2006; ISO 14044 2006].

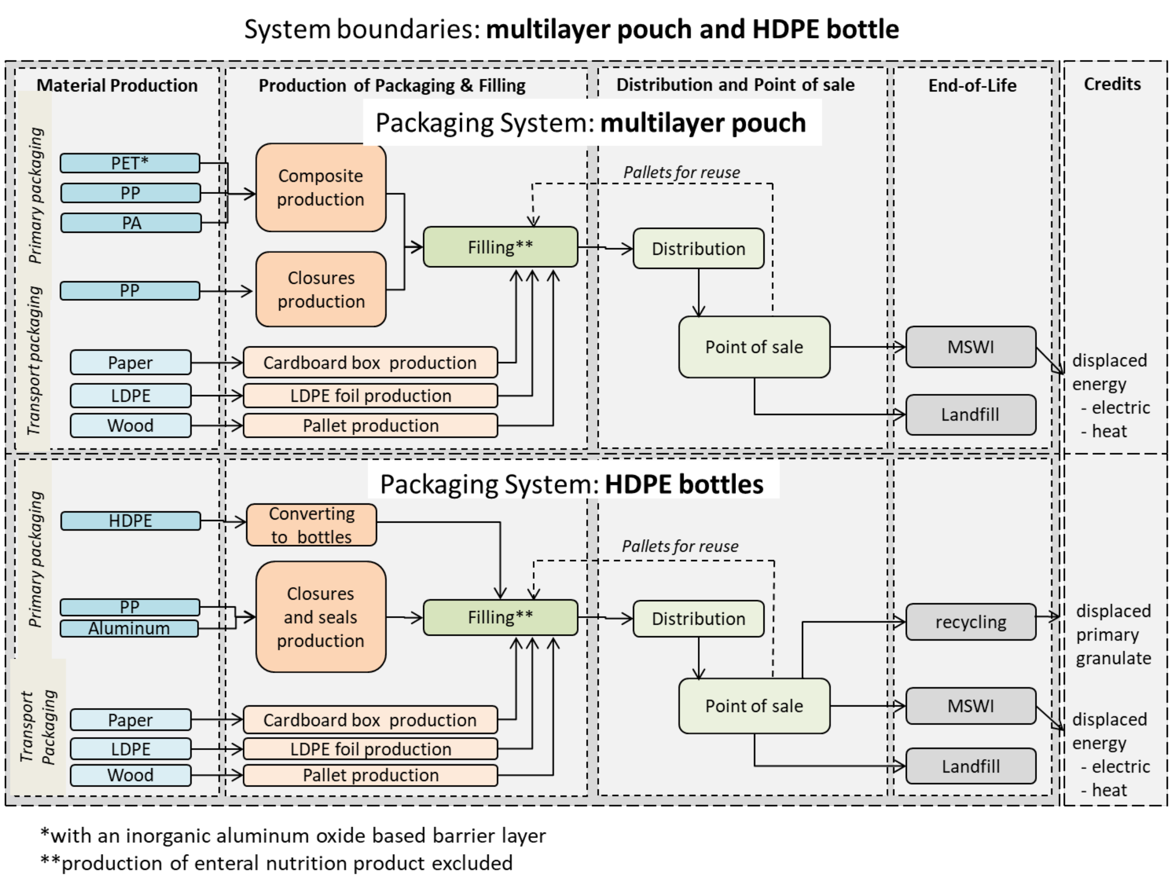
## 2.1 Functional unit

The LCA in this study is designed as an attributional "cradle-to-grave" LCA and includes the extraction and production of packaging raw materials, converting and filling processes, all transports as well as recycling and/or final waste disposal (landfill and/or incineration) of the packaging materials after their use. Attributional LCA methodology is selected as clearly the study aims to examine and compare environmental impacts of the two examined packaging product types that are common for enteral nutrition products. The LCA is based on the ISO 14040/14044 principles [ISO 14040 2006; ISO 14044 2006].

## 2.2 System boundaries

The study is designed as a 'cradle-to-grave' LCA, in other words it includes the extraction and production of raw materials, converting processes, filling processes, all transports and the final disposal or recycling of the packaging system. Mechanical recycling (only applicable for HDPE bottles) is calculated as open loop recycling, because currently commercially available HDPE mechanical recycling processes are lacking certification according to standards for food-grade recyclate quality. Figure 1 illustrates the system boundaries of the multilayer pouch and the HDPE bottles..

*Figure 1: System boundaries of multilayer pouch and HDPE bottles*



### 2.3 Geographical and temporal reference

The study is based on a cluster geographical approach. Europe and relevant oversea export to Latin America and Australia are considered.

The European cluster includes both Germany as well as European export countries, because distribution takes place predominantly by truck. Regarding the end-of-life phase, most relevant European countries are clustered by the predominant treatment method for residual waste fractions – either landfill or incineration. The cluster approach is based on the weighted average for Germany and the European export countries. This means that a weighted average of distribution distances (720 km for the European cluster) was formed based on the sales for the different countries to better depict the product distribution.

Countries where statistical data on end-of-life routes based on Eurostat indicates ~100 % incineration are: Germany, Austria, the Netherlands, Sweden, Belgium, Switzerland, Denmark, Norway and Finland. In France, incineration is the predominant route, so France is also assigned to the incineration cluster. Countries where landfill is the predominant practice are the UK, Spain and Poland. In Italy, the ratio between the two practices is 50:50 [Eurostat 2016].

For the most relevant overseas countries (Brazil, Argentina, Chile and Australia), distribution is a combination of sea container transport and truck. None of those countries have relevant incineration infrastructure, thus landfill is the treatment method of residual waste for the Latin American and Australian export country cluster. For the Latin American cluster the distance for the transport by ship is 10000 km and for the Australian market 20600 km. The distances are calculated with the tool from EcoTransIT World [EcoTransIT World 2019].

Time reference of the study is the year 2018 or as close as possible to that time period regarding data availability.

*Table 1: Environmental indicators and method references*

| Impact indicator | Approach | Characterization factor |
|---|---|---|
| **Climate change** (global warming) [kg $CO_2$-equivalents] | CML 2002 | IPCC 2013 |
| **Acidification** [kg $SO_2$-equivalents] | Heijungs et al. 1992 | CML 2010 |
| **Photochemical oxidants formation** [$O_3$-equivalents] | Carter 2010 | Carter 2010 |
| **Aquatic eutrophication** [PO4-equivalents] | Heijungs et al. 1992 | CML 2010 |
| **Terrestrial eutrophication** [kg PO4-equivalents] | Heijungs et al. 1992 | CML 2010 |
| **Particulate matter: PM2.5** [kg PM2.5-equivalents] | De Leeuw 2002, Heldstab et al 2003 | De Leeuw 2002, Heldstab et al 2003 |
| **Non-renewable primary energy** [MJ] | Inventory level | Inventory level |

### 2.4 Allocation

The study was laid out as an attributional cradle-to-grave LCA study. Correspondingly, a distinction is made between process-related and system-related allocation.

Regarding the system-related allocation, the 50:50 allocation methodology was applied. This method has been used in numerous LCAs carried out by ifeu and is the standard approach applied in the packaging LCAs commissioned by the German Environment Agency (UBA) [UBA 2000].

For the process-related allocation, economic allocation was applied as a general approach.

### 2.5 Environmental indicators/ environmental impact assessment

In the present study, midpoint impact categories are applied. The seven environmental indicators shown in Table 1 are taken into account in the present study.

A further indicator, ozone depletion potential, is also taken into account. Due to inventory data symmetry issues regarding emissions specifically relevant for ozone depletion potential, the indicator is not part of the base scenario results. Results including the further indicator are found in the supplementary material/appendix.

### 2.6 End of life routes

The end of life settings depend on the product. The multilayer pouches as a composite packaging type are expected to completely end up on a waste-for-disposal route. HDPE bottles on the other hand are expected to partly end up in a material recycling route, whereas the remaining non-recycled share is expected to end up on the waste-for-disposal route as well. The material recycling is assumed to be an open-loop material recycling route, as for the time being no food HDPE bottle with post-consumer recycled content exists, as commercially existing HDPE recycling processes are lacking a food-grade certification.

For the waste-for-disposal route either landfill or incineration with energy recovery is assumed. Both scenarios are calculated for the European cluster, as both options exist within the examined European markets. For the oversea export markets only the landfill option was taken into account because in Latin America as well as in Australia landfill is the predominant end-of-life route. [Ministerio del Medio Ambiente Gobierno de Chile 2018; Devincenzi 2018; Pickin et al. 2018] Both packaging types are expected and thus assumed to end up equally in the country-specific recovery route. The only difference is the mechanical recycling option for HDPE bottles as described in section 3.3.

Methodology regarding impact assessment of marine littering as part of life cycle assessments is currently in a development phase (and consensus building on agreed methodology still needs to be carried out within the LCA community). Hence, this aspect has not been taken into account for the comparative LCA. In general, both packaging types are polymer-based and thus may eventually contribute to marine littering.

### 2.7 Data collection

Key focus areas for data collection are the packaging specifications as well as recycling rates for HDPE bottles, as those are expected to be key parameters due to their influence on overall material mass flows. Primary data was collected in those fields as part of the present LCA study. Primary data collection was either carried out by measurement (e.g. weights of components of multilayer pouch and HDPE bottle weights), or is generated based on data obtained from hospitals directly, where necessary combined with further (published) data sources. The latter approach is used for determination of recycling quotas of hospital plastic packaging waste.

## 3 LIFE CYCLE INVENTORY AND DATA SOURCES

### 3.1 Packaging specifications

Presenius Kabi provided data for the primary packaging specifications for both the multilayer pouch system as well as HDPE bottles[1] currently on the market. Examined HDPE bottles cover the weight range found on markets on different continents [Fresenius Kabi 2019]. For multilayer pouch systems, also data on secondary and tertiary packaging was provided by Fresenius Kabi, along with information on transport packaging for HDPE bottle systems. Both the HDPE bottles and their respective closures show higher weights (up to 350%) than the multilayer pouch system. The following Table 2 shows the weights of all package components as they are used in the present study. The HDPE bottles contain a barrier layer (barrier material: ethylene vinyl alcohol (EVOH)) which was excluded from the calculation due to missing data regarding EVOH share in HDPE bottles. If it were included the results for the HDPE bottle would become even higher, thus by leaving it out a conservative approach in favor of the HDPE bottle was chosen.

### 3.2 Foreground and background processes

Further, distribution data (distance and means of transport) related to the multilayer pouch system and the respective target markets were provided by Fresenius Kabi. Corresponding settings are assumed for HDPE bottle systems examined. Data gaps remaining after the primary data collection process are complemented based on the ifeu-internal database (e.g. converting, filling processes, missing data on packaging specifications). In addition, also generic data published by industry associations such as Plastics Europe (in this study for datasets for HDPE, PP and PET), [FEFCO 2015] or [EcoTransIT World 2016] were used as well as the ecoinvent database. The country specific electricity mixes were obtained from a master network for grid power modelling and annually updated at ifeu as described in [ifeu 2016]. It is based on national electricity mix data by the International Energy Agency (IEA) . Umberto® was used as modelling software. Due to a lack of primary data, e.g. for the filling process, values were based on generic data. The filling process was calculated the same for all product systems. The impact of aseptic filling versus autoclave treatment plays only a minor role and therefore has not been taken into consideration in this study.

### 3.3 Recycling rates of HDPE bottles

A key characteristic of HDPE bottle systems versus the multilayer pouch system is the mechanical recycling option. To find out about the specific recycling rate for packaging waste (specifically for rigid HDPE bottles) from enteral nutrition products in hospitals, primary data were collected in the present study from several German hospitals as well as recycling companies. For that purpose, interviews with hospital employees in Germany as well as with disposal companies or recollection systems that are active on the German packaging waste market are conducted in order to collect primary data. The results of these interviews together with reference rates for recycling in hospitals lead to the rate used in this study. For a more detailed description of the process, see the supplementary material/appendix. Data collected led to an estimated recycling rate of 15 %. The 15% recycling rate was used in the present study as the basic setting.

1 Samples of HDPE bottles 500 mL and 1000mL globally present on the market for enteral nutrition products were weighted and their minimum and maximum weights were identified.

2 Lack of data for the transport packaging and pallet configuration: the exact pallet configuration and weight of stretch foil per pallet for the competing products is not known, therefore assumptions were made. Those assumptions can be regarded to be conservative regarding the multilayer pouch system.

*Table 2: Packaging specifications of the examined product systems [2]*

| | 500 mL | | | 1000 mL | | |
|---|---|---|---|---|---|---|
| | **Multilayer pouch** | **HDPE bottle A MIN** | **HDPE bottle B MAX** | **Multilayer pouch** | **HDPE bottle A MIN** | **HDPE bottle B MAX** |
| **Primary Packaging [g]** | **13.2** | **28.2** | **40.9** | **19.7** | **40.5** | **69.0** |
| Bottle / pouch [g] | 11.7 | 23.8 | 37.1 | 18.2 | 36.3 | 65.0 |
| Bottle / pouch closure [g] | 1.5 | 4.0 | 3.4 | 1.6 | 3.9 | 3.7 |
| Aluminum in closure [g] | *N/A* | *0.4* | *0.4* | *N/A* | *0.4* | *0.4* |
| **Secondary Packaging [g]** | **492.0** | **413.0** | **285.0** | **330.0** | **328.0** | **343.0** |
| Cardboard box [g] | 492.0 | 413.0 | 285.0 | 330.0 | 328.0 | 343.0 |
| *[Cardboard box corresponding to pouch/bottle [g]]* | *[33.0]* | *[34.0]* | *[36.0]* | *[41.0]* | *[41.0]* | *[43.0]* |
| **Transport Packaging [g]** | **22330.0** | **22330.0** | **22330.0** | **22330.0** | **22330.0** | **22330.0** |
| Stretch foil per pallet [g] | 330.0 | 330.0 | 330.0 | 330.0 | 330.0 | 330.0 |
| Pallet (Euro) [kg] | 22.0 | *22.0* | *22.0* | *22.0* | *22.0* | *22.0* |
| **Pallet configuration** | | | | | | |
| Bottle / pouch per box | 15.0 | 12.0 | 8.0 | 8.0 | 8.0 | 8.0 |
| Boxes per layer | 9.0 | 9.0 | 15.0 | 15.0 | 15.0 | 15.0 |
| Layers per pallet | 8.0 | 10.0 | 10.0 | 5.0 | 5.0 | 5.0 |
| Bottles/pouches per pallet | 1080.0 | 1080.0 | 1200.0 | 600.0 | 600.0 | 600.0 |

# 4 RESULTS

## 4.1 Climate change impacts

Figure 2 illustrates overall climate change impacts related to the multilayer pouch system (shown as green bars) for the European cluster. Orange bars indicate the range of climate change impacts as found for the lighter and heavier weight HDPE bottles as present on the market, with the

[3] http://www.iea.org/statistics/

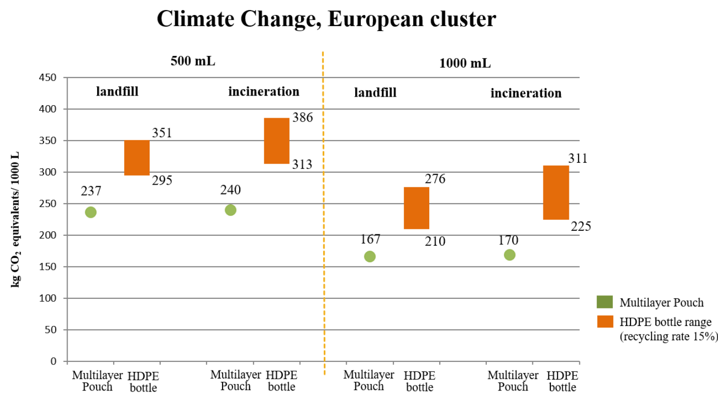



*Figure 2: Climate change result multilayer pouch vs. HDPE Bottle (recycling rate 15%), European cluster (500 mL and 1000 mL packages)*

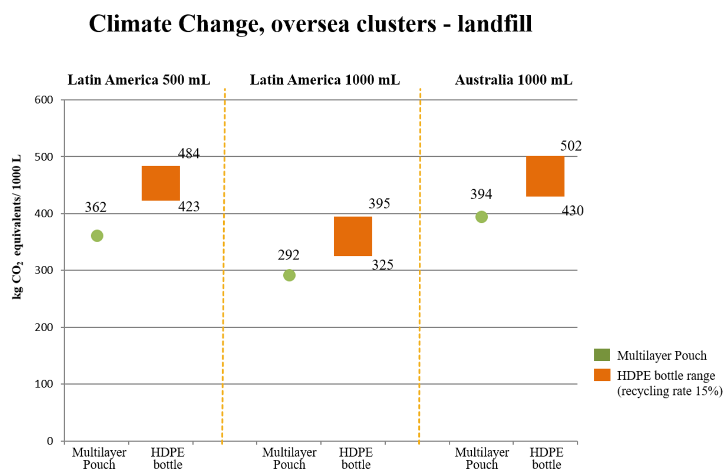



*Figure 3: Climate change result multilayer pouch vs. HDPE Bottle (recycling rate 15%), export countries (500 mL and 1000 mL packages)*

lower end of the orange bar representing the lighter bottle A. From this, it is clear that the multilayer pouch system is associated with lower greenhouse gas emissions than HDPE bottles for enteral nutrition, both for 500 mL as well as 1000 mL packages. It applies also both for European countries where landfill disposal routes are predominant as well as for countries where considerable share or up to 100% of residual waste ends up in an incineration plant. In addition, Figure 3 shows the results for the export countries, Latin America and Australia.

For example, in the landfill scenario for the 500 mL packages the result for the multilayer pouch is 237 kg CO2e/1000 L nutrition product. The results for the HDPE bottle in the same scenario vary between 295 kg CO2e/1000 L (for the lighter bottle) and 351 kg CO2e/1000 L nutrition product (for the heavier bottle).

### 4.2 Further environmental impacts

In the following, the results for all examined indicators are shown. The results are presented in individual tables for each geographic cluster and bottle size. Table 3-A represents the results for the European cluster with landfill for the bottle size of 500 mL. In Table 3-G the results for Australia, landfill, 1000 mL are presented. Units for the environmental indicators are:

Climate Change: t $CO_2$ equivalents / 1000 L

Aquatic Eutrophication: kg $PO_4$ equivalents / 1000 L

Terrestrial Eutrophication: kg $PO_4$ equivalents / 1000 L

Acidification: kg $SO_x$ equivalents / 1000 L

Photochemical Oxidants Formation: kg $O_3$ equivalents / 1000 L

Particulate Matter: kg PM2.5 equivalents / 1000 L

CED (non-renewable): GJ / 1000 L

## 5 DISCUSSION

### 5.1 Comparative result pattern for all indicators

When looking at the overall environmental performance, thus taking into account the full set of environmental indicators (see Figure 4 to Figure 10), it becomes apparent that the heavier HDPE bottle is the packaging system associated with the highest environmental impacts. The figure format sets each highest indicator result to 100%, thus illustrates the indicator results of other examined packaging systems (multilayer pouch and the lighter HDPE bottle A) relative to that reference system. Although the differences expressed as percentages vary by indicator, the common pattern over all indicators is that the multilayer pouch system (green bar) is associated with lower environmental impacts than both HDPE bottle systems. This corresponds to a favorable performance of the multilayer pouch for enteral nutrition from an environmental point of view.

The observed comparative result pattern applies to both examined packaging sizes (500 mL and 1000 mL), as well as all geographic clusters (Europe, Latin America, Australia).

*Table 3-A: Results for all indicators Europe, landfill, 500 mL*

| Environmental indicator | multilayer pouch | HDPE bottle A MIN | HDPE bottle B MAX |
|---|---|---|---|
| **Climate change** | 0.237 | 0.295 | 0.351 |
| **Aquatic Eutrophication** | 0.06 | 0.08 | 0.1 |
| **Terrestrial Eutrophication** | 0.07 | 0.08 | 0.09 |
| **Acidification** | 0.59 | 0.76 | 0.9 |
| **Photochemical Oxidants Formation** | 0.61 | 0.8 | 1.11 |
| **Particulate Matter** | 0.56 | 0.72 | 0.86 |
| **CED (non-renewable)** | 4.5 | 6.98 | 9.05 |

*Table 3-B: Results for all indicators Europe, incineration, 500 mL*

| Environmental indicator | multilayer pouch | HDPE bottle A MIN | HDPE bottle B MAX |
|---|---|---|---|
| **Climate change** | 0.24 | 0.313 | 0.386 |
| **Aquatic Eutrophication** | 0.05 | 0.07 | 0.09 |
| **Terrestrial Eutrophication** | 0.07 | 0.07 | 0.09 |
| **Acidification** | 0.53 | 0.67 | 0.77 |
| **Photochemical Oxidants Formation** | 0.58 | 0.74 | 1.04 |
| **Particulate Matter** | 0.51 | 0.65 | 0.75 |
| **CED (non-renewable)** | 3.95 | 6.06 | 7.76 |

*Table 3-C: Results for all indicators Latin America, landfill, 500 mL*

| Environmental indicator | multilayer pouch | HDPE bottle A MIN | HDPE bottle B MAX |
|---|---|---|---|
| **Climate change** | 0.362 | 0.423 | 0.484 |
| **Aquatic Eutrophication** | 0.06 | 0.08 | 0.1 |
| **Terrestrial Eutrophication** | 0.27 | 0.29 | 0.31 |
| **Acidification** | 2.75 | 2.99 | 3.19 |
| **Photochemical Oxidants Formation** | 0.92 | 1.11 | 1.43 |
| **Particulate Matter** | 2.58 | 2.81 | 2.99 |
| **CED (non-renewable)** | 6.17 | 8.7 | 10.82 |

*Table 3-D: Results for all indicators Europe, landfill, 1000 mL*

| Environmental indicator | multilayer pouch | HDPE bottle A MIN | HDPE bottle B MAX |
|---|---|---|---|
| **Climate change** | 0.167 | 0.21 | 0.276 |
| **Aquatic Eutrophication** | 0.04 | 0.05 | 0.08 |
| **Terrestrial Eutrophication** | 0.05 | 0.06 | 0.07 |
| **Acidification** | 0.4 | 0.53 | 0.69 |
| **Photochemical Oxidants Formation** | 0.44 | 0.58 | 0.93 |
| **Particulate Matter** | 0.38 | 0.5 | 0.66 |
| **CED (non-renewable)** | 3.35 | 4.97 | 7.34 |

*Table 3-E: Results for all indicators Europe, incineration, 1000 mL*

| Environmental indicator | multilayer pouch | HDPE bottle A MIN | HDPE bottle B MAX |
|---|---|---|---|
| **Climate change** | 0.17 | 0.225 | 0.311 |
| **Aquatic Eutrophication** | 0.03 | 0.05 | 0.07 |
| **Terrestrial Eutrophication** | 0.04 | 0.05 | 0.07 |
| **Acidification** | 0.35 | 0.46 | 0.58 |
| **Photochemical Oxidants Formation** | 0.42 | 0.54 | 0.88 |
| **Particulate Matter** | 0.35 | 0.45 | 0.58 |
| **CED (non-renewable)** | 2.97 | 4.32 | 6.26 |

*Table 3-F: Results for all indicators Latin America, landfill, 1000 mL*

| Environmental indicator | multilayer pouch | HDPE bottle A MIN | HDPE bottle B MAX |
|---|---|---|---|
| **Climate change** | 0.292 | 0.325 | 0.395 |
| **Aquatic Eutrophication** | 0.04 | 0.05 | 0.08 |
| **Terrestrial Eutrophication** | 0.25 | 0.26 | 0.28 |
| **Acidification** | 2.55 | 2.69 | 2.91 |
| **Photochemical Oxidants Formation** | 0.75 | 0.88 | 1.24 |
| **Particulate Matter** | 2.4 | 2.52 | 2.73 |
| **CED (non-renewable)** | 5.02 | 6.52 | 8.95 |

*Table 3-G: Results for all indicators Australia, landfill, 1000 mL*

| Environmental indicator | multilayer pouch | HDPE bottle A MIN | HDPE bottle B MAX |
|---|---|---|---|
| **Climate change** | 0.394 | 0.43 | 0.502 |
| **Aquatic Eutrophication** | 0.04 | 0.05 | 0.08 |
| **Terrestrial Eutrophication** | 0.45 | 0.47 | 0.50 |
| **Acidification** | 4.77 | 4.95 | 5.24 |
| **Photochemical Oxidants Formation** | 1.04 | 1.18 | 1.55 |
| **Particulate Matter** | 4.47 | 4.64 | 4.91 |
| **CED (non-renewable)** | 6.4 | 7.93 | 10.40 |

### 5.2 Sectoral results for climate change: Key drivers of environmental impacts

Figure 11 shows the sectoral results for the category climate change (European cluster, packaging size 500 mL). The sectoral results depict the individual life cycle elements in the two stacked columns. Each color represents a life cycle step from the polymer or film, packaging as well as closure production, throughout the filling, the transport packaging and the distribution to the recycling and disposal of the empty packages. The product system also receives credits for carbon storage (which is the paper-related uptake of CO2 from the atmosphere in wood during tree growth), energy and material. The credits are illustrated as negative results in the graph. These credits are subtracted from the sum of the other life cycle steps leading to the net result, represented by the grey bar. The grey bar represents the net indicator result, which forms the basis for comparison between examined systems.

The results show that the landfill scenario has lower greenhouse gas emissions than the incineration scenario. A look at the graph reveals that only the greenhouse gas emissions of the step ‘recycling and disposal’ increase, this is due to the released CO2 from combustion of carbon in the incineration process. On the negative part of the axis, also the credit energy increase however, the net results increase compared to landfill. The grey bars are the net results, which represent the overall figure including the environmental burdens and credits. The chart further reveals that the results for climate change for the multilayer pouch system are in both cases clearly lower than the ones for the HDPE bottles.

The results for the other clusters and packaging sizes can be found in the supplementary material/ appendix. For the oversea export markets the distribution phase is of more significance due to the longer transport distances. Overall, the basic statement remains over all packaging sizes and geographic clusters

### 5.3 Further results and sensitivity analysis

Besides base scenario results for selected European and Latin American clusters presented in the previous sections, further results for other clusters (with other geographic reference / end-of-life route) have been calculated.

For the 500 mL packaging systems the

*Figure 4: LCA Results of multilayer pouch versus HDPE bottles (15% RQ) Europe, 500 mL, incineration*

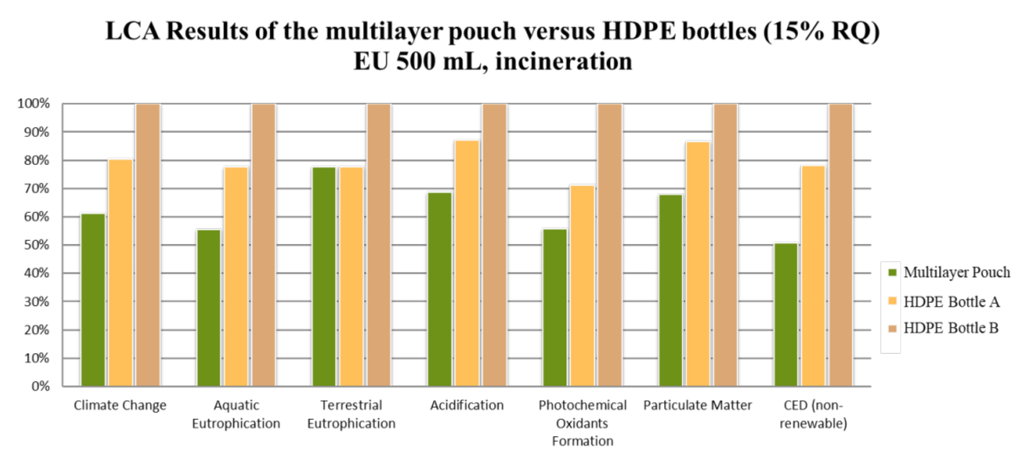


*Figure 5: LCA Results of multilayer pouch versus HDPE bottles (15% RQ) Europe, 500 mL, landfill*

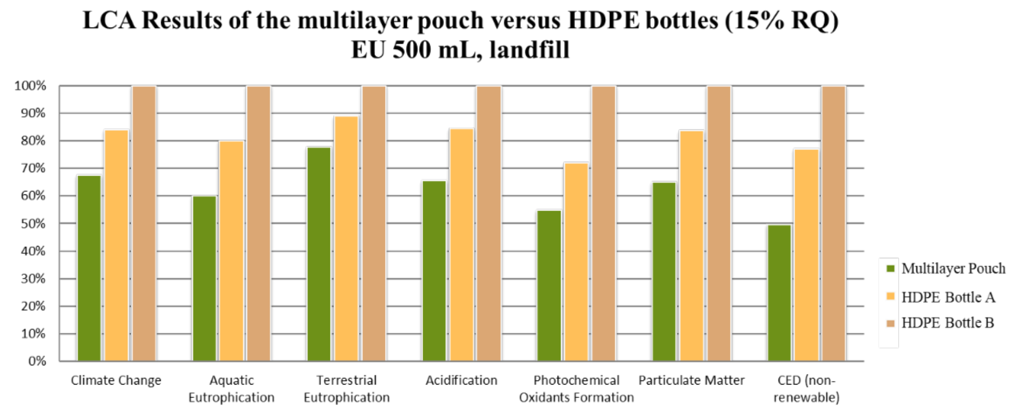



*Figure 6: LCA Results of multilayer pouch versus HDPE bottles (15% RQ) Latin America, 500 mL, landfill*

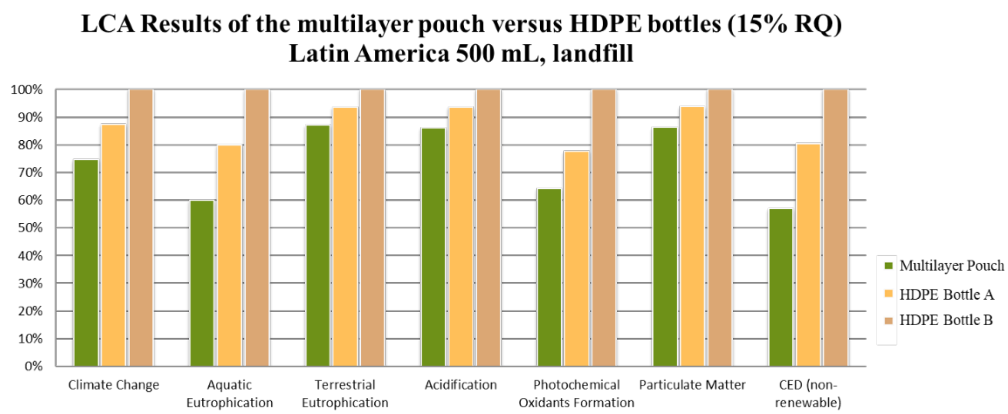



*Figure 7: LCA Results of multilayer pouch versus HDPE bottles (15% RQ) Europe, 1000 mL, incineration*

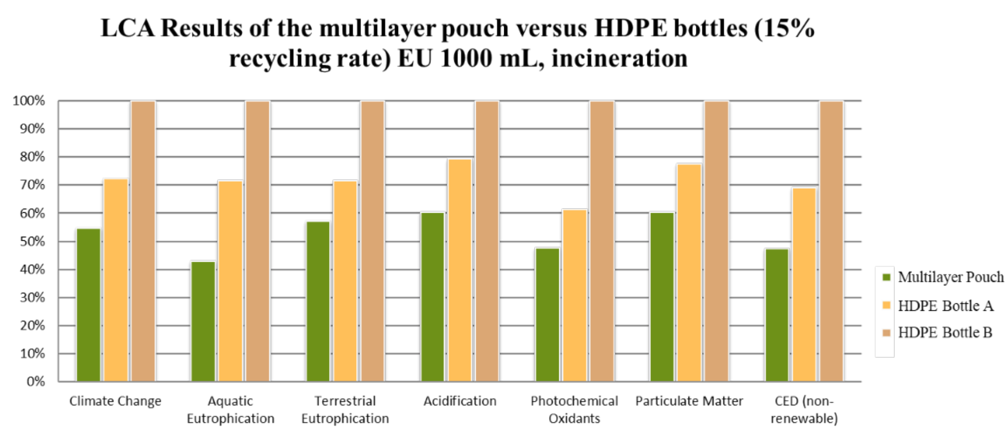


*Figure 8: LCA Results of multilayer pouch versus HDPE bottles (15% RQ) Europe, 1000 mL, landfil*

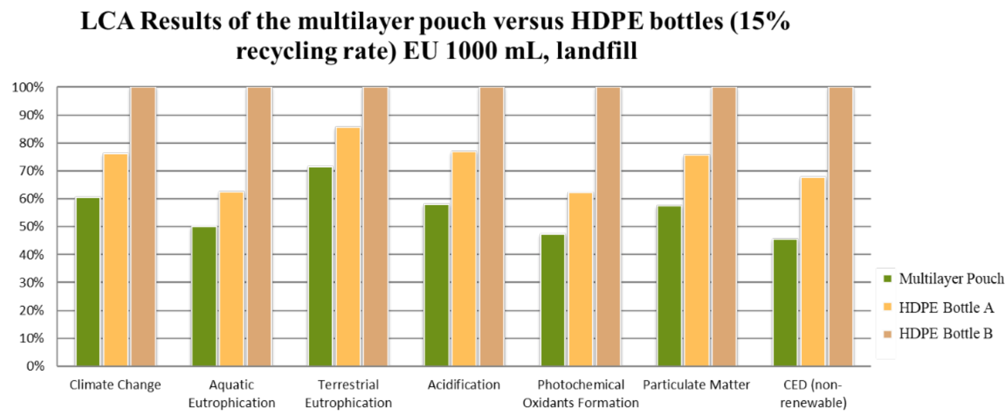



*Figure 9: Results of multilayer pouch versus HDPE bottles (15% RQ) Latin America, 1000 mL, landfill*

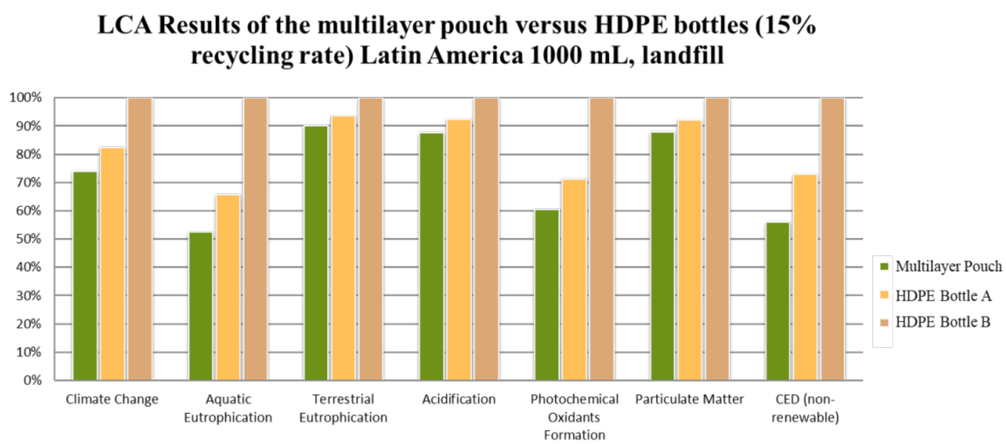
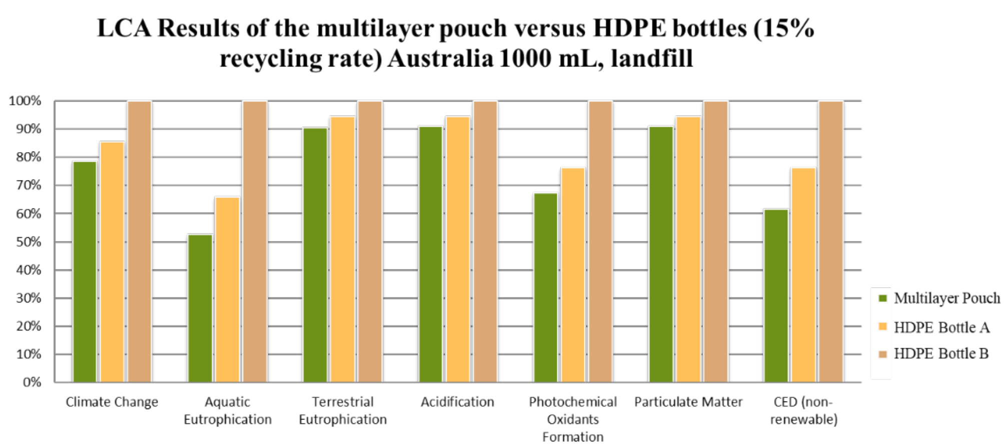



*Figure 10: LCA Results of multilayer pouch versus HDPE bottles (15% RQ) Australia, 1000 mL, landfill*

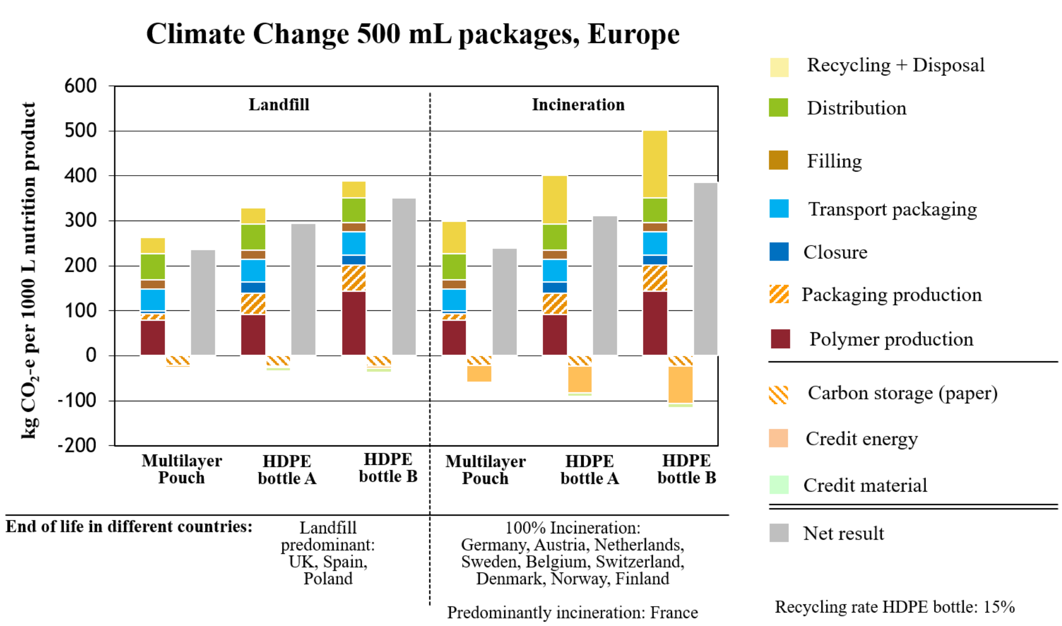


European cluster and the one for Latin America were examined. For the 1000 mL packaging systems, Australia was added as an additional cluster, as in this case 1000 mL is the predominant size on the market. Hence, the 1000 mL packaging systems were examined for all three geographic clusters (Europe, Latin America and Australia). Regarding the end-of-life route, the landfill scenario was calculated for all clusters, because it applies to all clusters. For the European cluster an incineration scenario was calculated in addition because that practice is common in many European countries. Seven clusters were examined in total. In all clusters examined, the multilayer pouch is associated with overall lower environmental impacts than both HDPE bottles. Related results for Europe, Latin America and Australia are found in the supplementary material/appendix.

The results shown in the previous sections assumed a recycling rate of 15 % for used HDPE bottles as the basic setting. This 15% recycling rate for HDPE bottle packaging waste in hospitals is considerably lower than the average European plastic waste recycling rate of 30 % [European Parliament 2018]. Although the very specific situation in hospitals means the household recycling rate cannot be applied, a sensitivity analysis was nevertheless undertaken using a recycling rate of 30%, reflecting activities observed also in the hospital setting expected to increase plastic packaging recycling rates in the future.

The sensitivity analysis was done for the smaller packaging size (500 mL) in the European cluster. As a result of the increased recycling rate the observed environmental impacts for recycling and disposal life cycle steps increase for the HDPE bottles. At the same time the credits for energy and material increase even more, which lead to an overall lower net result (which is e.g. better in respect to climate change). Compared to the results with a recycling rate of 15 %, the net results decrease by 2 % for both bottle types in both, incineration and landfill clusters. However, the multilayer pouch still shows a considerably lower (and thus favorable) result

*Figure 11: Sectoral results climate change, 500 mL, Europe*



compared to both HDPE bottles. The sensitivity analysis shows that the results are stable also with a higher recycling rate for the HDPE bottles. Related results are found in the supplementary material/ appendix.

In addition to the sensitivity analysis for the recycling rate, an additional environmental indicator has been calculated: stratospheric ozone depletion. This indicator was excluded from the main analysis (and the result presentation in the result section of this article) because of considerable limitations regarding underlying inventory data quality for air emissions specifically contributing to stratospheric ozone depletion. The authors of this study see too large limitations in underlying data quality in order to derive comparative statements between HDPE-based and PET-based (the multilayer pouch) packaging systems. The full picture including the stratospheric ozone depletion results can nevertheless be seen in the supplementary material for transparency reasons. Although the multilayer pouch shows higher results in this indicator (caused by one specific air emission strongly contributing to stratospheric ozone depletion), it is necessary to keep in mind at this point that even if one does consider the stratospheric ozone depletion indicator for comparative results, the overall finding of favorable environmental impacts for the multilayer pouch system versus the HDPE bottle system would remain stable in any case.

## 6 CONCLUSION AND OUTLOOK

This Life Cycle Assessment compared a multilayer pouch with two HDPE bottles (light and heavy) on the market for enteral nutrition products in Europe, Latin America and Australia. The results show that the comparable lighter multilayer pouch is associated with overall lower environmental impacts than the heavier HDPE bottles on the market with a 15% mechanical recycling quota. This means that the multilayer pouch packaging system is favorable from an environmental point of view versus alternative HDPE bottle systems in the field of enteral nutrition products. The study thus reveals that a non-recyclable, lightweight flexible container for packing of enteral nutrition products can perform better (thus have lower potential environmental impacts) compared to heavier recyclable rigid containers for packing of enteral nutrition products.

This observed comparative result pattern between multilayer pouch and HDPE bottles applies to both examined packaging sizes (500 mL and 1000 mL), as well as all geographic clusters examined (Europe, Latin America, Australia). The percentage difference of the potential environmental impact of both packaging types varies across packaging sizes and clusters, but the comparative result pattern (multilayer pouch lower environmental impact than HDPE bottles) remains the same, even if longer distribution distances become relevant. Those findings are also valid for the additional clusters and furthermore remain stable against several sensitivity analyses (e.g. with 30% recycling quota) carried out, results of which are shown in the supplementary material/appendix.

In the following, an outlook for future research and further discussion is given. A key issue for future discussion is how both packaging types are suitable for circular economy. Especially in the field of clinical nutrition products high hygiene standards are essential which impedes circular economy. Nonetheless, further R&D activities are needed to develop packaging that corresponds to circular economy criteria. Nevertheless, the above presented LCA findings shall be reviewed once innovative technologies enabling circularity of examined packaging components for such clinical applications are starting to become commercially available on the market. Besides the ability to be a part of circular economy it is also important to ensure to keep the material in its (closed) loop. Therefore specific regulations might be necessary in order to assure high recovery rates and suitable recovery pathways of used packaging materials.

## REFERENCES


[1] UBA, 2019. Umweltbundesamt, Dessau-Roßlau (Hrsg.): Aufkommen und Verwertung von Verpackungsabfällen in Deutschland im Jahr 2017

[2] European Commission, 2018. A European Strategy for Plastics in a Circular Economy, COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS, Brussels 16.01.2018

[3] REMONDIS, 2017. REMONDIS Medison GmbH - Krankenhausabfälle - Abfälle aus der humanmedizini-schen oder tierärztlichen Versorgung, https://www.abfallmanager-medizin.de/themen/krankenhausabfaelle-abfaelle-aus-der-humanmedizinischen-oder-tieraerztlichen-versorgung/ (accessed 14 May 2020)

[4] Berufsgenossenschaft für Gesundheitsdienst und Wohlfahrtspflege (BGW), 2019: Abfallentsorgung Informationen zur sicheren Entsorgung von Abfällen im Gesundheitsdienst; https://www.bgw-online.de/SharedDocs/Downloads/DE/Medientypen/BGW%20Broschueren/BGW09-19-000_Abfallentsorgung_Download.pdf?__blob=publicationFile (accessed 13 October 2020)

[5] World Health Organization, 2020. Indicators: Current health expenditure (CHE) as percentage of gross domestic product (GDP) (%); https://www.who.int/data/gho/data/indicators/indicator-details/GHO/current-health-expenditure-(che)-as-percentage-of-gross-domestic-product-(gdp)-(-) (accessed 13 October 2020)

[6] Leiden, A.; Cerdas, F.; Noriega, D.;Beyerlein, J.; Herrmann, C., 2020. Life cycle assessment of a disposable and a reusable surgery instrument set for spinal fusion surgeries, Resources, Conservation & Recycling 156, 104704

[7] Statistisches Bundesamt, 2020. Eckdaten der Krankenhauspatientinnen und -patienten – Aus dem Krankenhaus entlassene vollstationäre Patientinnen und Patienten (einschließlich Sterbe- und Stundenfälle), Stand 28-08-2020, https://www.destatis.de/DE/Themen/Gesellschaft-Umwelt/Gesundheit/Krankenhaeuser/Tabellen/entlassene-patienten-eckdaten.html (accessed 19 October 2020)

[8] Ali, M.; Wang, W.; Chaudhry, N., 2016. Application of life cycle assessment for hospital solid waste management: A case study; Journal of the air & waste management association, Vol. 66; No. 10, 1012-1018

[9] Fresenius, 2019. Annual report, https://www.fresenius.com/media_library/Fresenius_Annual_Report_2019.pdf

[10] Environmental management – Life cycle assessment – Principles and framework (ISO 14040:2006); German and English version EN ISO 14040:2006.

[11] Eurostat, 2016. Municipal waste by waste management operations; https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_wasmun&lang=en (accessed 18 May 2020)

[12] EcoTransIT World, 2016. Berechnung, https://www.ecotransit.org/calculation.de.html (accessed 19 October 2020)

[13] UBA, 2000. Umweltbundesamt. Berlin (Hrsg.): Ökobilanz für Getränkeverpackungen II. Hauptteil, UBA-Texte 37/00,Berlin, 2000.

[14] CML, 2002. Guinée. J.B. (Ed.) Centre of Environmental Science - Leiden University (CML). de Bruijn, H; van Duin, R; Huijbregts,M; Lindeijer; E;. Roorda, A; van der Ven, B; Weidema; B: Handbook on Life Cycle Assessment. Operational Guide to the ISO Standards, Eco-Efficiency in Industry and Science Vol. 7, Kluwer Academic Publishers, The Netherlands

[15] IPCC, 2013. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cam-bridge, United Kingdom and New York, NY, USA, 1 535 pp.

[16] Heijungs R., Guinèe J., Lankreijer RM., Udo de Haes HA., Wegener Sleeswijk., 1992. Environmental life cycle assessment of products – Guide. Novem, rivm, Centre of Environmental Science (CML), Leiden, The Netherlands

[17] CML, 2010. CML-IA database that contains characterisation factors for life cycle impact assessment (LCIA) for all baseline characterization methods mentioned in [CML 2002]. Database CML-IAv3.7, Institute of Environmental Sciences, Leiden University, Leiden, November 2010; http://www.cml.leiden.edu/software/data-cmlia.html

[18] Carter, W. P. L., 2010. Development of the SARC-07 Chemical Mechanism and Updated Ozone Reactivity Scales. Updated Chemical Mechanisms for Airshed Model Applications. Supplementary Material. California Air Resources Board

[19] De Leeuw. F., 2002. A set of emission categories for long-range transboundary air pollution. Bilthoven

[20] Heldstab, J., de Haan, P., Künzle, T., Keller, M., Zbinden, R., 2003. Modelling of PM10 and PM2.5 ambient concentrations in Switzerland 2000 and 2010, Environmental Documentation No.169. Swiss Agency for the Environment, Forests and Landscape SAEFL, Bern

[21] Ministerio del Medio Ambiente Gobierno de Chile, 2018. Cuarto Reporte del Estado del Medio Ambiente; https://sinia.mma.gob.cl/wp-content/uploads/2019/01/Cuarto-reporte-del-medio-ambiente-compressed.pdf

[22] Devincenzi, A., 2018. El Cronista - Producción de basura: cuál es la realidad en Argentina y qué se pordría hacer, https://www.cronista.com/responsabilidad/Produccion-de-basura-cual-es-la-realidad-en-Argentina-y-que-se-podria-hacer-20180302-0075.html (accessed 14 May 2020)Pickin, J., Randell, P., Trinh, J., Grant, B., 2018. National Waste Report 2018, Department of the Environment and Energy Australia, Blue Environment Pty Ltd

[23] Fresenius Kabi, 2019. Personal communication

[24] FEFCO, 2015. Fédération Européenne des Fabricantes de Papiers pour Ondulé (FEFCO) and Cepi Container Board: European Database for Corrugated Board Life Cycle Studies. Brussels, 2015.

[25] EcoTransIT World, 2016. Ecological Transport Information Tool for Worldwide Transports- Methodology and Data Update. EcoTransIT World Initiative (EWI) .Berne, Hannover, Heidelberg. June 2016

[26] Ifeu, 2016. Fehrenbach, H., Lauwigi, C., Liebich, A., Ludmann, S.: Documentation for the UMBERTO based ifeu electricity model. (download December 2019 https://www.ifeu.de/wp-content/uploads/Documentation-IFEU-Electricity-Model-2016-06.pdf)

[27] European Parliament, 2018. Plastic waste and recycling in the EU: facts and figures; https://www.europarl.europa.eu/news/en/headlines/society/20181212STO21610/plastic-waste-and-recycling-in-the-eu-facts-and-figures (accessed 14 May 2020)

**SUPPLEMENTARY MATERIAL APPENDIX**

## A Interviews to determine the recycling rate for HDPE bottles

As public data related to recycling rates of HDPE bottle packaging waste from enteral nutrition products in hospitals are missing, an expert estimation procedure is carried out within the screening LCA study.

For that purpose, interviews with hospital employees in Germany as well as with disposal companies or recollection systems that are active on the German packaging waste market are conducted in order to collect primary data.

With each group, four interviews are carried out. The results of the interviews with the disposal companies can be summed up with following facts:

- the recycling rate for the lightweight packaging fraction is relatively high in the hospital sector compared to households
- the rate refers to the market quantity of packages; 30 % of all hospitals dispose their packaging waste through industry solutions
- the disposal companies named 40 % and 68 % as rates for material recycling with regard to the quantity delivered (only for industry solutions)
- the quality of the plastic fraction is above average for industry solutions
- in hospitals where the lightweight packages are processed through the dual system, the recycling rate is much lower (less than 30 %). There the material recycling is difficult because packages from the infirmaries are collected together with those from the cafeteria, which lowers the quality.
- Furthermore, sources for packaging waste from the infirmaries are:
    - bottles and canisters for detergents
    - bottles and canisters for hand cleaning agents
    - bottles and canisters for hand sanitizers
    - infusion bottles for saline solutions, glucose, etc.
    - packaging foils for medical need
    - medical packaging; drinking cups
    - non-packaging of similar material
    - Packaging for tube feeding or liquid food were only named after explicit inquiry

The interviews with the hospital employees revealed other insights that are summed up in the following. The interviewees stated that there are bins for residual waste but none for recyclable materials in the patient rooms. The bins for reusable materials are usually where medicine is stored and infusions are prepared. The packages are usually collected before the administration of the medications or products and a separate collection does not happen in the patient rooms but in an extra room. Since there is typically no separate collection for recyclable materials in the patient rooms, empty packages like infusion bottles or bottles for tube feeding are disposed with the residual waste on all internal stations. The intensive care unit is an exception, it has bins for reusable materials in the patient rooms. As a result, it can be assumed that if 10 % of all patients who receive tube feeding are on intensive care, only 10 % of all packages for tube feeding are collected separately. Consequently, 90 % are disposed through the residual waste. Another exception are the ‘isolation rooms’. Waste that comes from them has to be disposed separately and cannot be recycled.

Beyond that, the hospital employees added some other remarks, like that there is a low ‘problem awareness’ regarding waste sorting. However a quality management for waste disposal exists, it is usually covered through hygiene management. The interviewees also stated that the HDPE bottle market for tube feeding is insignificant compared to the market for infusion bottles, a disposal concept for HDPE infusion bottles could be very helpful for hospitals.

Table 1 shows reference rates for the recycling of plastic packaging from hospitals and an estimated mean value. The statements regarding the connection rate of the hospitals to industry solutions overestimate its relevance. Therefore, the estimated material recycling rate is based on the relevance of the system with regard to the market volume. Based on this calculation, the recycling rate for all plastic packaging types through all stations is 28 %.

| | Quota | Share of affiliated hospitals | Quota | Share of relevant market volume |
|---|---|---|---|---|
| Industry Solution A | 68% | 30% | 68% | 18% |
| Industry Solution B | 40% | 7% | 40% | 4% |
| Dual System in Hospitals (infirmary with cafetaria) | 15% | 28% | 15% | 35% |
| Dual System in Hospitals (infirmary only) | 20% | 35% | 20% | 43% |
| weighted average | 34% | | **28%** | |

*Supplementary table 1: Overview reference rates in hospitals and estimated mean value*

Due to the following reasons, the recycling rate for HDPE bottles for enteral nutrition is significantly lower.

- The bottles are emptied in the patient rooms
- The hospital stuff does not have time to bring the bottles to the recycling stations
- The bottles are not completely emptied

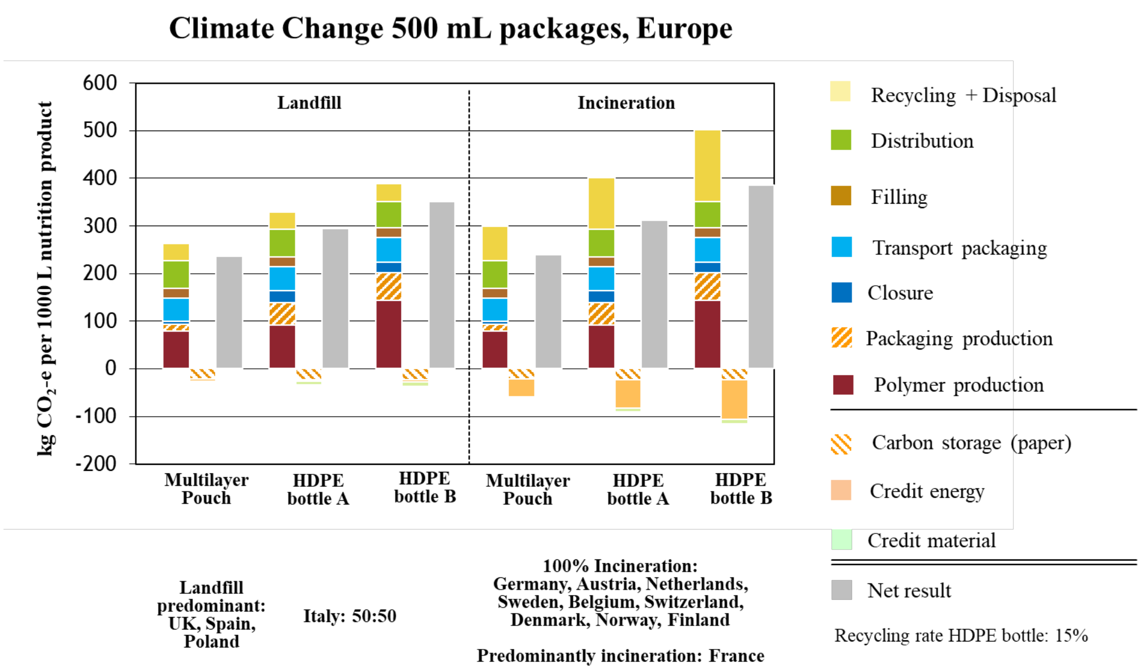
- The bottles are only a marginal part of the total amount of plastic waste
- The bottles usually occur occasionally

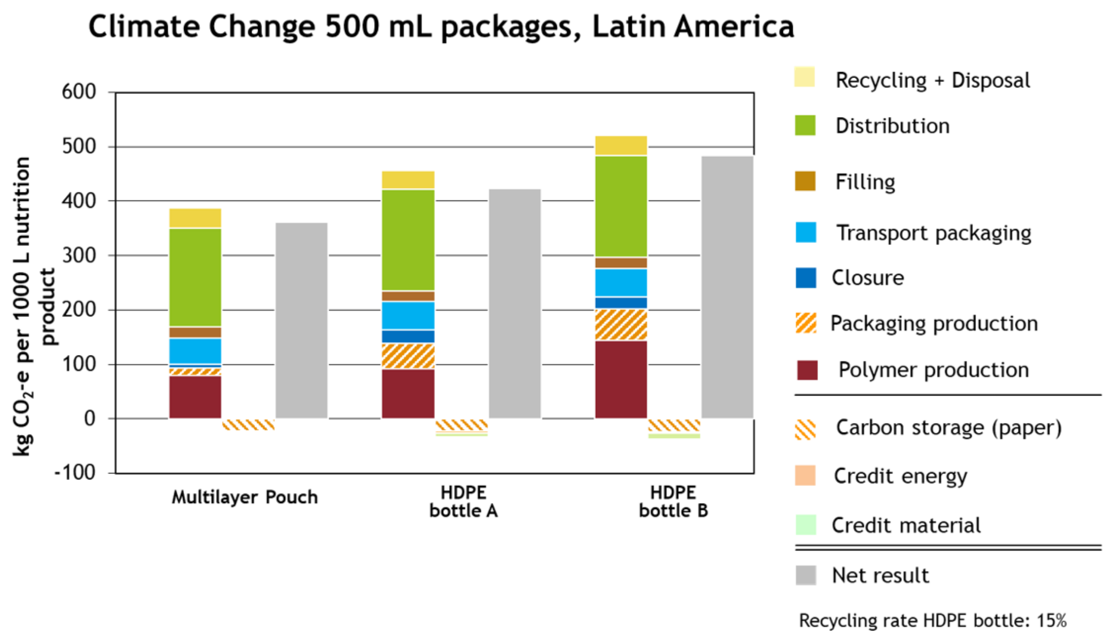
Taking into consideration all the available data, the estimated recycling rate for HDPE bottles is estimated to **15 %**, with a range of 10 % to 18 %. This recycling rate is assumed for the HDPE bottle system under study.

### *B Additional result figures*

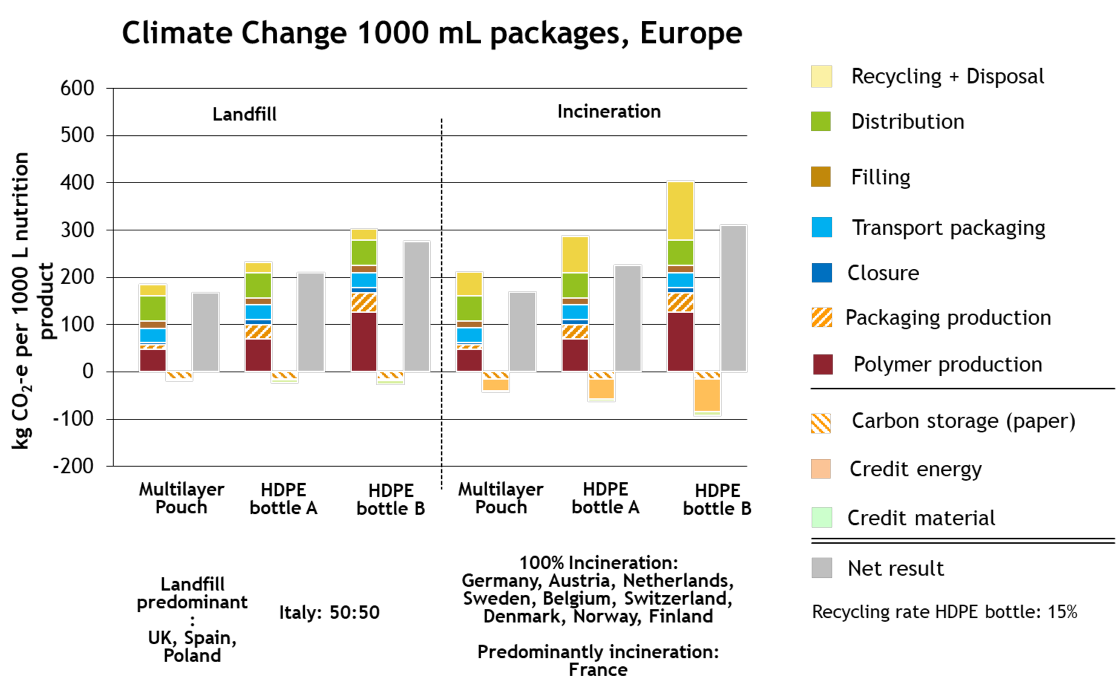
Additional result figures: sectoral result figures for all packaging sizes and geographic clusters for the indicator climate change, one sectoral result figure for acidification, sensitivity analysis sectoral results for 500mL packages climate change, result figures for all examined packaging sizes and geographic clusters including ozone depletion potential

Sectoral result figures climate change:

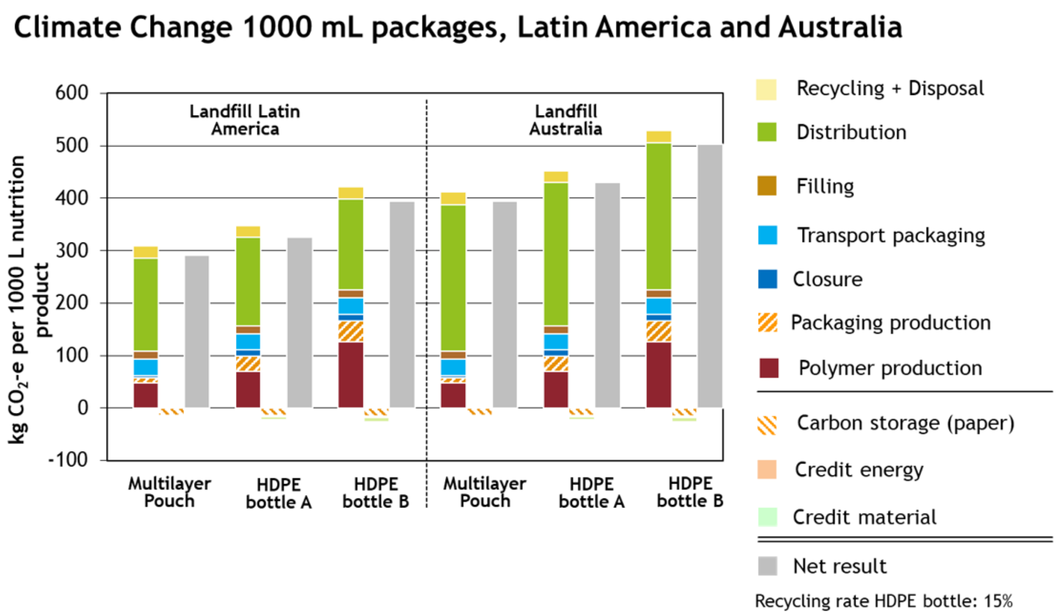




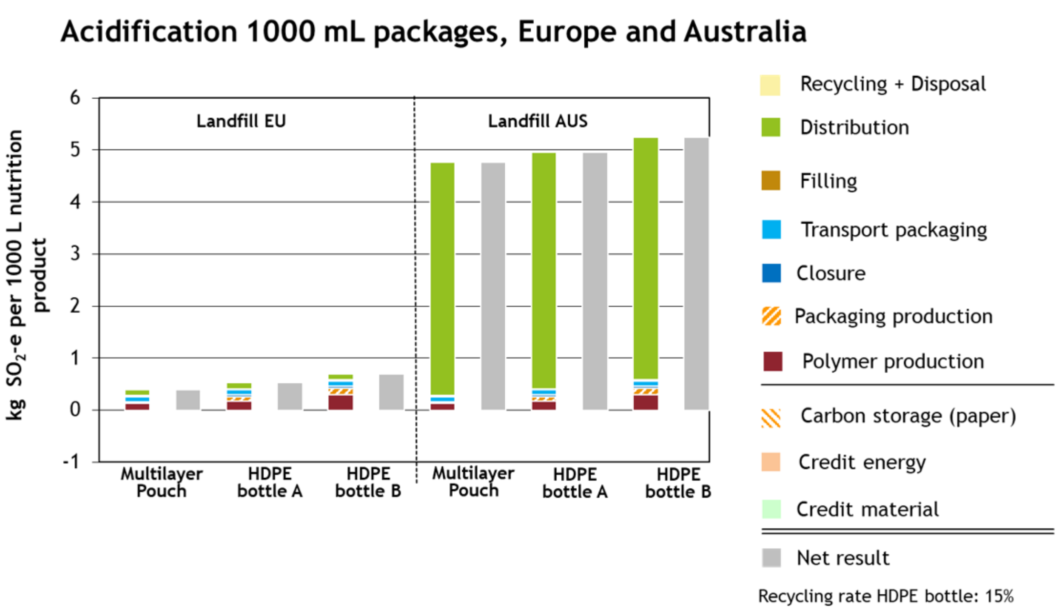
Climate Change 500 mL packages, Latin America
kg CO2-e per 1000 L nutrition product
600
500
400
300
200
100
0
-100
Multilayer Pouch
HDPE bottle A
HDPE bottle B
Recycling + Disposal
Distribution
Filling
Transport packaging
Closure
Packaging production
Polymer production
Carbon storage (paper)
Credit energy
Credit material
Net result
Recycling rate HDPE bottle: 15%

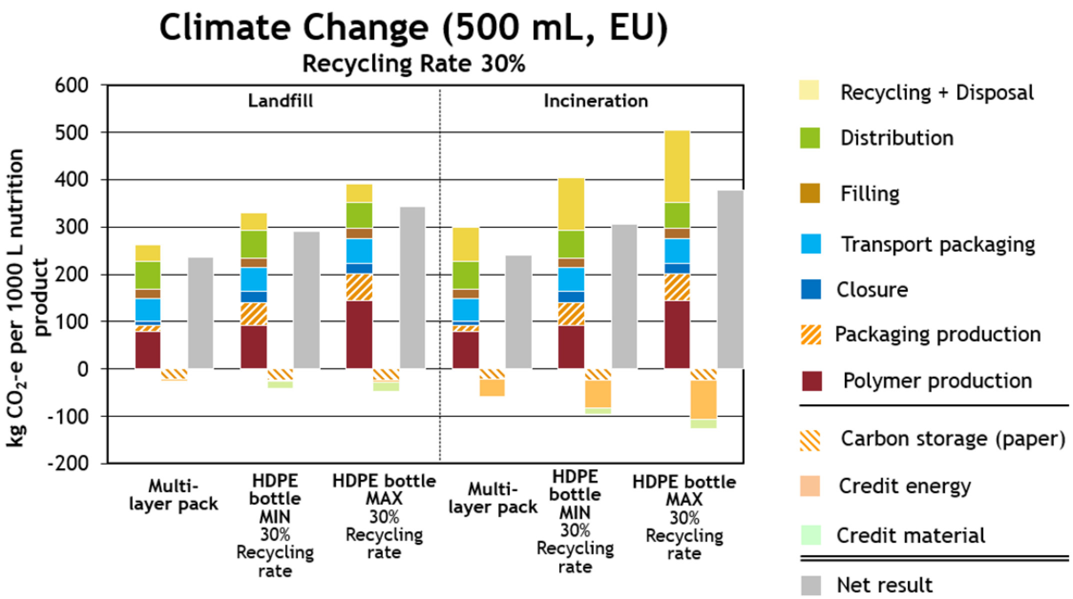
Climate Change 1000 mL packages, Europe
kg CO2-e per 1000 L nutrition product
600
500
400
300
200
100
0
-100
-200
Landfill
Incineration
Multilayer Pouch
HDPE bottle A
HDPE bottle B
Multilayer Pouch
HDPE bottle A
HDPE bottle B
Landfill predominant : UK, Spain, Poland
Italy: 50:50
100% Incineration: Germany, Austria, Netherlands, Sweden, Belgium, Switzerland, Denmark, Norway, Finland
Predominantly incineration: France
Recycling + Disposal
Distribution
Filling
Transport packaging
Closure
Packaging production
Polymer production
Carbon storage (paper)
Credit energy
Credit material
Net result
Recycling rate HDPE bottle: 15%



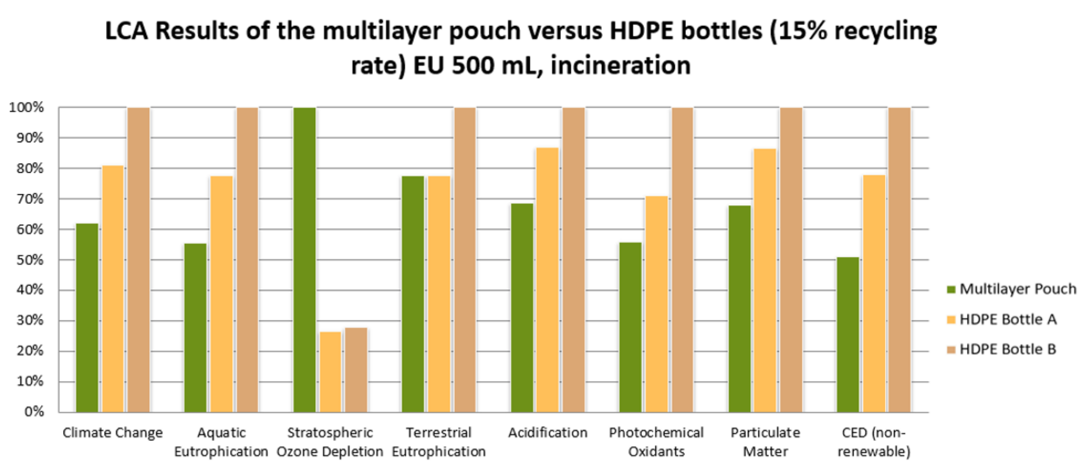

Sectoral result figure acidification:

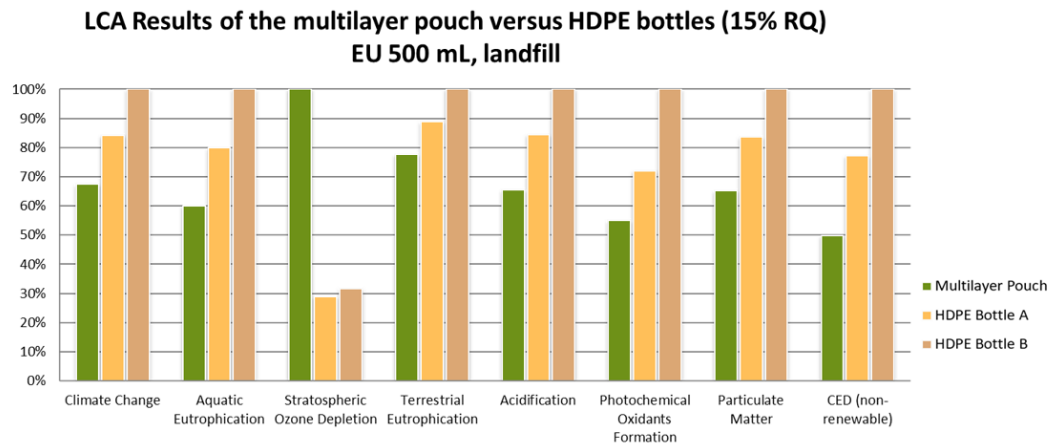


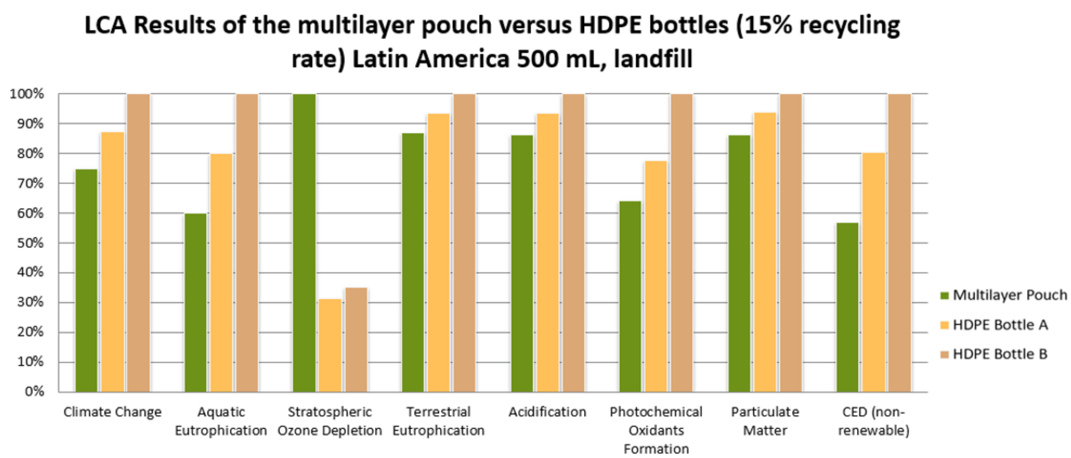
Sensitivity analysis: 30 % recycling rate for HDPE bottles:

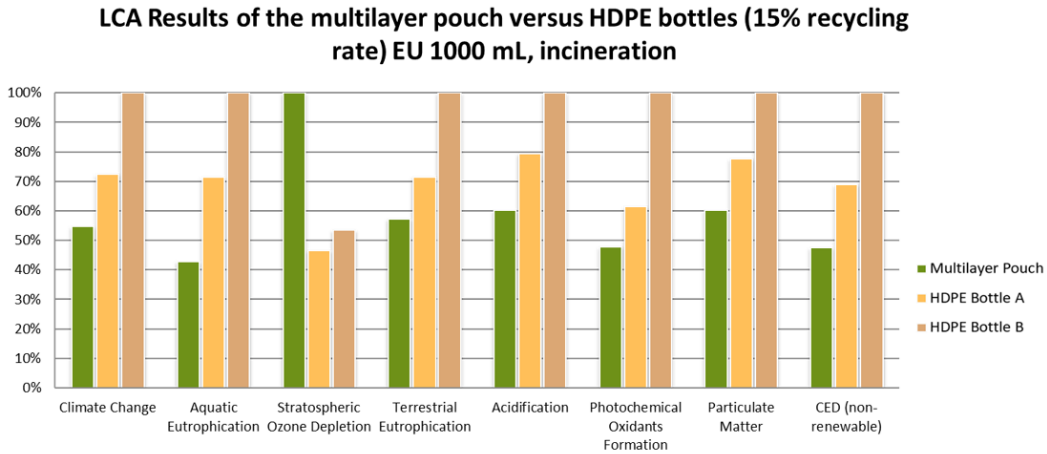


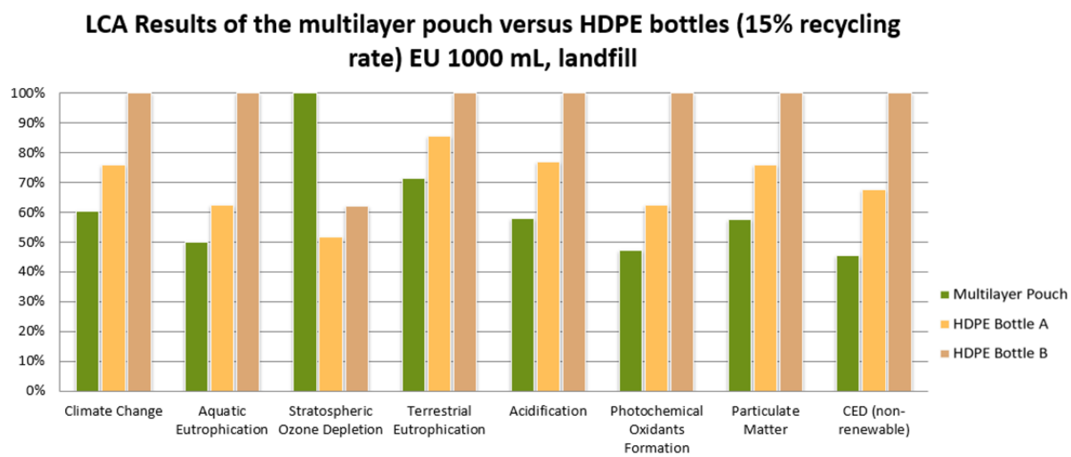

All results including additional indicator ozone depletion potential:

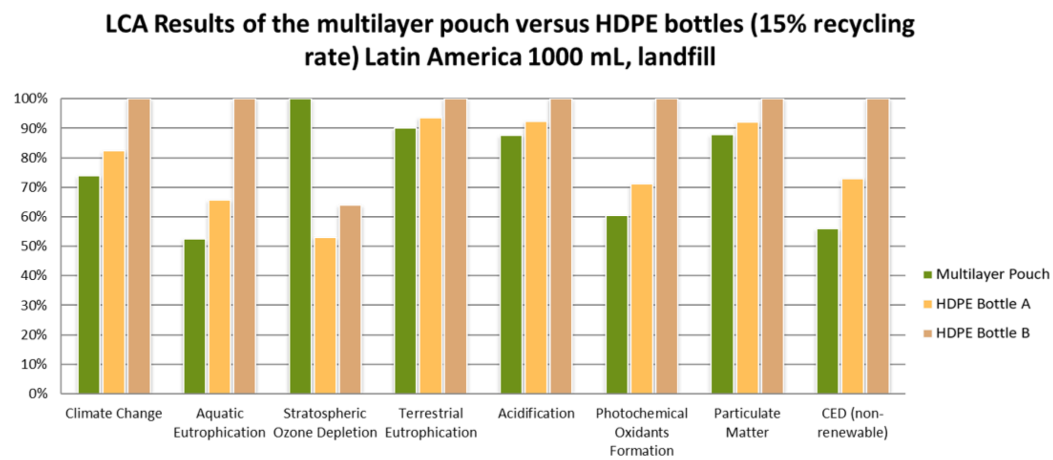


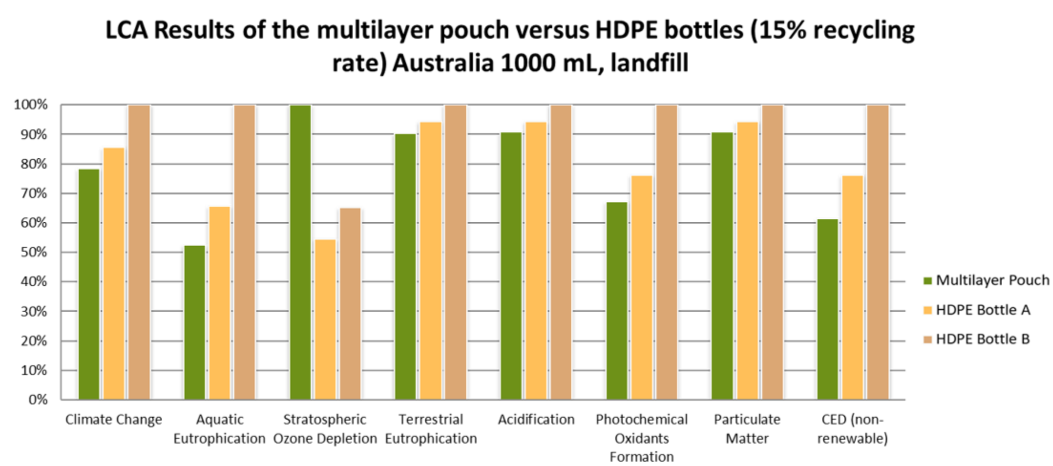

LCA Results of the multilayer pouch versus HDPE bottles (15% RQ)
EU 500 mL, landfill
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Climate Change
Aquatic Eutrophication
Stratospheric Ozone Depletion
Terrestrial Eutrophication
Acidification
Photochemical Oxidants Formation
Particulate Matter
CED (non-renewable)
Multilayer Pouch
HDPE Bottle A
HDPE Bottle B


LCA Results of the multilayer pouch versus HDPE bottles (15% recycling rate) Latin America 500 mL, landfill
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Climate Change
Aquatic Eutrophication
Stratospheric Ozone Depletion
Terrestrial Eutrophication
Acidification
Photochemical Oxidants Formation
Particulate Matter
CED (non-renewable)
Multilayer Pouch
HDPE Bottle A
HDPE Bottle B


LCA Results of the multilayer pouch versus HDPE bottles (15% recycling rate) EU 1000 mL, incineration
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Climate Change
Aquatic Eutrophication
Stratospheric Ozone Depletion
Terrestrial Eutrophication
Acidification
Photochemical Oxidants Formation
Particulate Matter
CED (non-renewable)
Multilayer Pouch
HDPE Bottle A
HDPE Bottle B


LCA Results of the multilayer pouch versus HDPE bottles (15% recycling rate) EU 1000 mL, landfill
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Climate Change
Aquatic Eutrophication
Stratospheric Ozone Depletion
Terrestrial Eutrophication
Acidification
Photochemical Oxidants Formation
Particulate Matter
CED (non-renewable)
Multilayer Pouch
HDPE Bottle A
HDPE Bottle B


LCA Results of the multilayer pouch versus HDPE bottles (15% recycling rate) Latin America 1000 mL, landfill
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Climate Change
Aquatic Eutrophication
Stratospheric Ozone Depletion
Terrestrial Eutrophication
Acidification
Photochemical Oxidants Formation
Particulate Matter
CED (non-renewable)
Multilayer Pouch
HDPE Bottle A
HDPE Bottle B


LCA Results of the multilayer pouch versus HDPE bottles (15% recycling rate) Australia 1000 mL, landfill
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Climate Change
Aquatic Eutrophication
Stratospheric Ozone Depletion
Terrestrial Eutrophication
Acidification
Photochemical Oxidants Formation
Particulate Matter
CED (non-renewable)
Multilayer Pouch
HDPE Bottle A
HDPE Bottle B